Cytosine Complexes with Copper(II) Perchlorate

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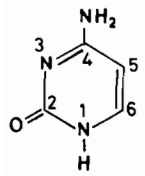
These laboratories have employed two different interaction media for the preparation of 3d metal perchlorate complexes with purine nucleobases, namely ethanol-triethyl orthoformate (teof) [1–3] and ethyl acetate (ea)-teof [4–7]. The latter medium generally favors more rapid complex precipitation and higher yields [4–7]. Ethanol-teof and ea-teof afford similar types of complexes, which differ occasionally as far as additional ligands are concerned (*i.e.*, ethanol *versus* aqua ligands) [1–7]. We were interested in extending our studies to include metal complexes with pyrimidine nucleobases, and we initiated work in this direction by employing our two synthetic methods for the preparation of $Cu(ClO_4)_2$ complexes with cytosine (cytH; **1**),



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which are dealt with in this communication. Numerous metal complexes of cytosine have been reported, including the adducts $Cu(cytH)_4(ClO_4)_2 \cdot ROH$ (R = CH_3, C_2H_5) and $Cu(cytH)_4(ClO_4)_2 \cdot 2H_2O$ [8, 9]. Regarding crystal structure determinations of metal complexes with cytosine and 1-substituted derivatives (e.g., 1-methylcytosine and cytidine), it was established that these ligands, when functioning as terminal unidentate, bind through the N3 nitrogen [10–15], with the sole exception of 1-methylcytosine binding through the N4 nitrogen of the NH_2 group in a Ru^{3+} complex [16]. When acting as bidentate, these ligands may chelate through N3, N4 [17] or N3 and the O2 carbonyl oxygen (semichelation in the latter case with substantially shorter M–N3 than M–O2 bonds) [18–21] or form bridges between adjacent metal ions, coordinating through N3, O2 [19, 22, 23] or N3, N4 [24, 25] in di- or polymeric structures. Spectral evidence favoring coordination of cytosine or cytidine solely through O2 was also presented for certain metal complexes [9, 26]. Finally, several cytosinium ($cytH_2^+$, protonated at N3 [27]) complexes with MCl_4^{2-} anions (M = Cu, Zn, Cd) involve H-bonding (NH– –Cl and CH– –Cl) interactions between the $cytH_2^+$ cation and the MCl_4^{2-} anion [28–32].

Experimental

The synthetic procedures employed were as follows: 1.25 mmol hydrated $Cu(ClO_4)_2$ was dissolved in a mixture of 15 ml teof and 35 ml of either ethanol or ea, and the solution was heated at 50 °C for 10 min, under stirring. Then, 2.5 mmol cytosine monohydrate were added and the resultant mixture was refluxed for 48 h (EtOH-teof) or 12 h (ea-teof). Following the refluxive step, the solid complex produced was separated by filtration, washed with anhydrous diethyl ether and stored *in vacuo* over anhydrous $CaSO_4$. The complex obtained from EtOH-teof was the violet $Cu(cytH)_4(ClO_4)_2$. *Anal.* Found (calc.): C, 27.6 (27.2); H, 3.2 (2.9); N, 23.85 (23.8); Cu, 9.0 (9.0); Cl, 9.7 (10.0)%. The green complex isolated from ea-teof contained both neutral cytH and anionic cyt^- ligands, as well as ea and 1½ ClO_4 groups per Cu atom. Its analysis corresponded to the $Cu_2(cytH)_3(cyt)(ea)(ClO_4)_3$ empirical formula: C, 25.3 (25.1); H, 3.1 (2.8); N, 17.6 (17.6); Cu, 13.4 (13.3); Cl, 10.6 (11.1)%. The absence of ν_{OH} bands in the IR of the new complexes confirms that no EtOH or water ligands are present in these compounds. Spectral and magnetic measurements were obtained by methods described elsewhere [33]. The violet complex shows limited solubility in nitromethane–acetone (1:1 *v/v*), and its molar conductivity in this medium (10^{-3} M solution at 25 °C) is 141 Ω^{-1} cm^2 mol^{-1}, corresponding to a 1:2 electrolyte. The green complex is insoluble in organic media.

Results and Discussion

The new violet Cu^{2+} complex is the alcohol-free analog of the $Cu(cytH)_4(ClO_4)_2 \cdot ROH$ (R = CH_3, C_2H_5) complexes previously reported by Goodgame and Johns [9]. Its solid-state (Nujol mull) d–d transition spectrum is characterized by a strong maximum at 543 and a shoulder at 687 nm (spectra of the alcoholate analogs, nm: R = CH_3 545s, 660sh; R = C_2H_5 540s, 685sh [9]). Relevant infrared spectral data are given in Table I. Several studies dealing with the IR spectra of cytosine [32, 34–37] and its metal complexes [9, 23, 32, 38] have appeared in the literature. The ν_{NH_2}, δ_{NH_2} and $\nu_{C=O}$ bands of cytH undergo only small changes upon formation of the violet complex, so that any strong bonding of cytH

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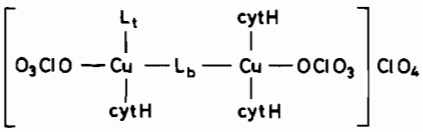
TABLE I. Relevant IR Spectral Data for cytH·H_2O and the New Cu^{2+} Complexes (cm^{-1})

cytH·H_2O [a]	$Cu(cytH)_4(ClO_4)_2$	$Cu_2(cytH)_3(cyt)(ea)(ClO_4)_3$	Band assignment
3450s			ν_{OH}
3375s, 3180s	3415s, 3335s, 3220s	3410s, 3340s, 3225s	ν_{NH_2}
3100s,sh, 2980m, 2920m	3100ms, 2970m, 2915m	3110ms, 2975m, 2920m	$\nu_{NH} + \nu_{CH}$
		1725m	$\nu_{C=O}$(ea) [b]
1703w, 1665s, 1645s	1693m, 1665vs, 1650vs	1702m, 1670vs, 1655vs, 1648vs	$\delta_{NH_2} + \nu_{C=O}$(cytH) [c]
1615s, 1600s,sh, 1575w, 1540m	1635s, 1610s, 1595s,sh, 1568m, 1530ms,b	1632s, 1610s, 1602s,sh, 1575m, 1525ms,b	$\nu_{C=C} + \nu_{C=N} + \delta_{NH}$
1290m	1297m	1312ms, 1299ms	$\nu_{C-NH_2} + \nu_{C-N} + \nu_{C-O}$(ea)
	1093vs,b	1120s, 1085vs,b, 1066s	$\nu_3(ClO_4)$
	920vvw,b	930w,b	$\nu_1(ClO_4)$
656m	650w	650w	d
	620m	631w, 662m, 612m	$\nu_4(ClO_4)$
548m	555ms,b	550mw,b	d
497m, 485m, 481m, 468m, 442m, 422m, 391w,sh	495m, 481m, 463m, 440m, 421m, 400w,sh, 350w,b, 330vw, 310w	500mw, 440mw, 420mw,b, 390w, 355w,b	ν_{cytH}(500–250 cm^{-1})
		470mw,b	$\nu_2(ClO_4)$
		322mw,b	$\nu_{Cu-O}(OClO_3)$
		303w,b	ν_{Cu-O}(ea)
	285mw, 278mw	277mw,b	ν_{Cu-N}

[a]Free cytH band assignments based on refs. 32, 34 and 35. [b]Free ea shows the $\nu_{C=O}$ and ν_{C-O} modes at 1740 and 1239 cm^{-1}, respectively [44]. [c]δ_{NH_2} and $\nu_{C=O}$ of cytosine were assigned at 1703 and 1662 cm^{-1}, respectively, by Susi *et al.*, who did not report the 1645 cm^{-1} band [34], and at 1665 and 1645 cm^{-1}, respectively, by Shirotake and Sakaguchi, who did not report the 1703 cm^{-1} absorption [32]. [d]The 656 cm^{-1} band was assigned as NH_2 wagging [32], whilst for the 548 cm^{-1} absorption the following assignments have been made: ring vibration [32], $\delta_{CO} + \delta_{CN}$ in phase [34], and ω_{NH_2} [36].

to Cu^{2+} through the C=O oxygen or the NH_2 nitrogen can be ruled out [32]. The $\nu_{C=C} + \nu_{C=N}$ bands of cytH show significant shifts and splittings in the spectrum of this complex, as would be expected for a compound involving N3-bonded cytH [32]. The ν_{Cu-N} bands are in the same region as those reported for the alcoholate analogs [9], while the ν_3 and $\nu_4(ClO_4)$ absorptions are single and indicative of the exclusive presence of ionic ClO_4^- [39, 40]. The magnetic moment of the violet complex at 300 K is normal (1.97 μ_B). The combined evidence favors the formulation of the complex as $[Cu(cytH)_4](ClO_4)_2$ with a square-planar CuN_4 chromophore. The compound is structurally similar to the corresponding alcoholates, since the latter do not involve coordinated methanol or ethanol [9]. The crystal structure of $Cu(cytH)_4(ClO_4)_2$·MeOH was briefly described as follows: The copper is surrounded by the four N3 nitrogen atoms of the cytH molecules, with the carbonyl oxygen atoms above and below the CuN_4 plane (two at 2.70 and two at 2.82 Å) [9]. This structure is analogous to that of $[Cu(pyrimidine\text{-}2\text{-}one)_4](ClO_4)_2$·EtOH, in which the square-planar CuN_4 unit is characterized by Cu–N distances of 1.992–2.004 Å, with the keto oxygen atoms lying in positions to form only very weak Cu–O bonds (Cu–O distances 2.776–2.901 Å) and the ethanol molecules and ClO_4^- ions not involved in coordination but participating in H-bonding [41, 42].

The new green complex is rather unusual in that it contains ea in addition to the cytosine ligands. It is also a mixed cytH–cyt^- complex, with cyt^- displacing one ClO_4^- group. Its stoichiometry, $Cu_2(cytH)_3(cyt)(ea)(ClO_4)_3$, insolubility in organic media and subnormal magnetic moment at 300 K (1.59 μ_B) are suggestive of a bi- or polynuclear structure [43]. The d–d transition spectrum of this complex is characterized by a single broad maximum at 615 nm. Its IR spectrum (Table I) exhibits bands associated with the ea ligand at 1725 ($\nu_{C=O}$), 1312 (ν_{C-O}) and 303 (ν_{Cu-O}) cm^{-1} [44]. In the $\nu_{C=O}$ and δ_{NH_2} regions of cytosine, four bands appear at 1702–1648 cm^{-1}, so that participation of the C=O oxygen or NH_2 nitrogen of some of the cytosine ligands present in the complex in binding is possible [17–25, 32]. In the $\nu_{C=C} + \nu_{C=N}$ region, the green complex shows a spectrum similar to that of the violet compound; this indicates N3 is also the primary binding site of cytosine in the green complex [32]. The ν_3 and $\nu_4(ClO_4)$ modes are triply split and the ν_1 and $\nu_2(ClO_4)$ modes are clearly IR-active. Consequently, the green complex contains both ionic ClO_4^- and unidentate coordinated $-OClO_3$ ligands [39, 40]. The tentative $\nu_{Cu-O}(OClO_3)$, ν_{Cu-O}(ea) and ν_{Cu-N} band assignments are consistent with coordination number four [9, 44, 45]. A likely binuclear structure for the complex is **2**, where L_t = ea and L_b = cyt^- or vice versa. Cytosine has been found to act as bi-



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dentate bridging N3,N4- or N3,O2-bonded in several metal complexes [19, 22–25], as already mentioned, so that $L_b = cyt^-$ is the most probable case. However, it is also conceivable that ea may function as bidentate bridging, with each of the COO oxygens binding to a different Cu^{2+} ion in the dimer [46, 47]. Synthetic studies of cytosine complexes with other 3d metal perchlorates are in progress, and a paper, including a more detailed characterization of the two Cu^{2+} complexes herein reported, will be published in the future.

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